# RELATIONSHIPS OF LOWER SILURIAN STRATA IN OHIO, WEST VIRGINIA, AND NORTHERN KENTUCKY[1]

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ABSTRACT

The Brassfield Formation, consisting mainly of carbonate strata, is overlain by beds of the Dayton Formation at several localities in southwestern Ohio, high on the east flank of the Cincinnati Arch. The Brassfield thickens eastward into the subsurface and becomes separated from the Dayton by an expanding wedge of shale and carbonate beds. The writer considers these beds to be equivalent to the middle and lower parts of the Noland Formation of Kentucky.

The northernmost outcrop of the Noland Formation occurs in Adams County in southern Ohio, but in the subsurface it can be traced farther north into Pike County and thence northeast to Guernsey County, Ohio. The lower Plum Creek Clay Member of the Noland continues into northern Ohio and Ontario, where it merges with the Cabot Head Shale. The Brassfield Formation can also be traced in the subsurface from the outcrop in Adams County northward into the Manitoulin Dolomite of Ontario.

Eastward, the Brassfield and part of the overlying Plum Creek Clay Member (in southern Ohio and in Kentucky) or the Cabot Head Shale (farther north) intertongue with the "Clinton" sandstone in central and eastern Ohio and the equivalent Tuscarora Formation in eastern Kentucky and West Virginia. The upper members of the Noland (Oldham, Lulbegrud, and Dayton) and part of the lower member can be traced from southern Ohio into the lower part of the Rose Hill Formation where it occurs in the subsurface of western West Virginia.

Although some geologists have failed to distinguish the different members of the Noland Formation from the Brassfield in subsurface studies, information from recent drill holes indicates that these can be traced from Kentucky into southern Ohio as separate stratigraphic units.

## INTRODUCTION

The report is part of a larger stratigraphic investigation of the Silurian Formations in Ohio and adjacent states (Horvath, 1964). The purpose of the investigation was to find whether rock units named for surface exposures were identifiable in the subsurface, the geographic extent of these identifiable units, and the stratigraphic equivalents of these units in Ohio, northern Kentucky, and West Virginia. During the course of the investigation, one problem in particular attracted the writer's attention. As the Silurian strata are traced eastward into the Appalachian Basin from outcrops in Ohio and Kentucky, a general thickening of the sedimentary section occurs. One important result is a greatly expanded section at the approximate position of the Brassfield. A number of geologists consider the additional units to be part of the Brassfield Formation. Should all these units be referred to the Brassfield, or are some of these units continuous with the Plum Creek, Oldham, and Lulbegrud Members of the Noland Formation of east-central Kentucky? Secondly, what are the stratigraphic equivalents of these rocks in the eastern and northern parts of the basin (West Virginia and northern Ohio), as determined from the subsurface tracing of these units?

Regional subsurface studies by Rittenhouse (1949) and Freeman (1951) are major contributions to an understanding of the Silurian in widely separated parts of the central and northern Appalachian Basin. During the past ten to fifteen years, additional drill holes have been located in strategic areas by oil companies in Ohio, West Virginia, and Kentucky. Thus, by means of modern subsurface data, it is now possible to trace many of the rock units between outcrops on opposite sides of the Basin.

Most of the data used in this study to extend the above-named stratigraphic

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units into the subsurface are from 80 drill holes (fig. 1, table 1). In addition, descriptions of measured sections were consulted, and the rock units were examined in the field at a number of outcrops.

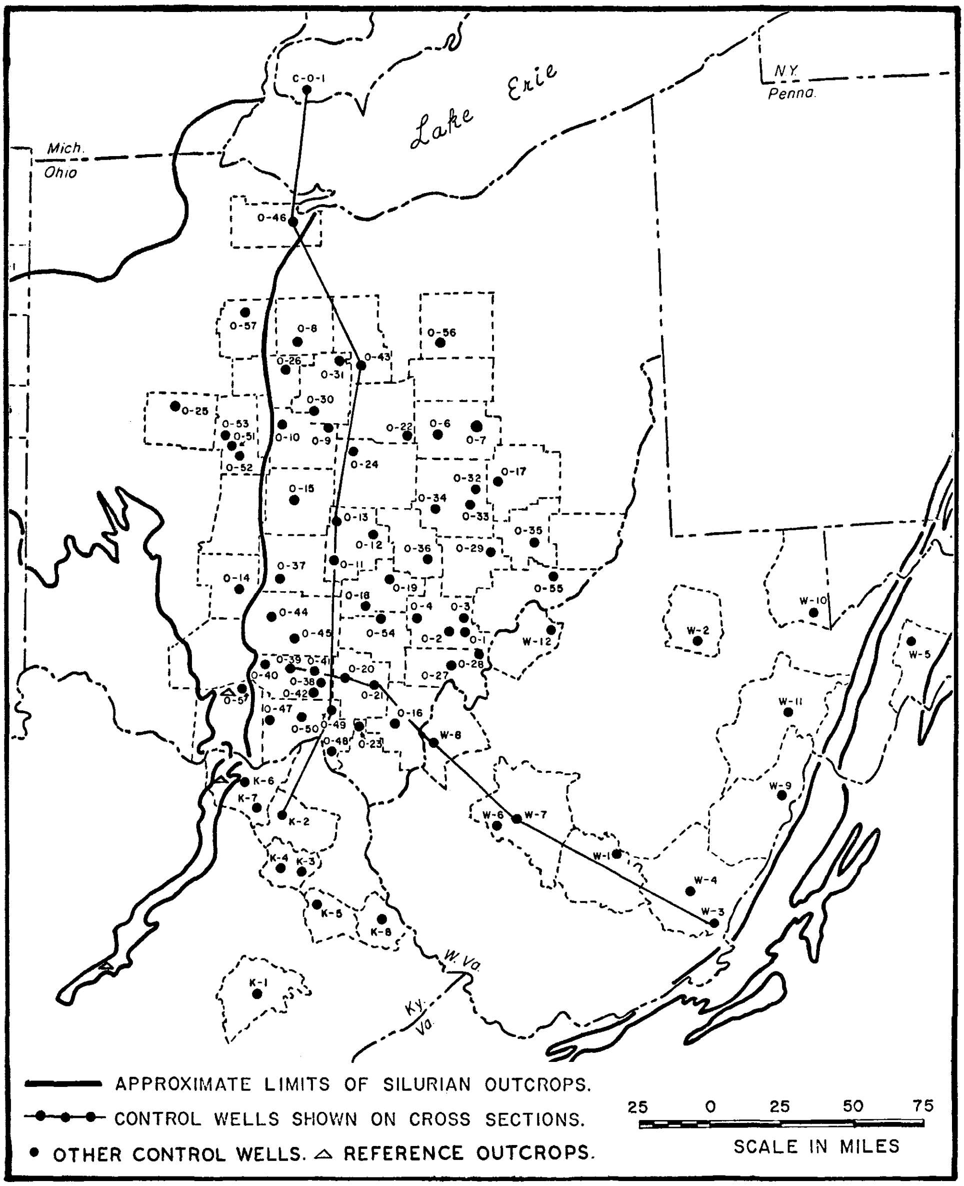


FIGURE 1. General Data Map showing location of drill holes and control wells which supplied subsurface information for this investigation.

TABLE 1

*Names and locations of drill holes supplying subsurface data*

| Map number | Name | Location | State permit or sample number |
|---|---|---|---|
| I-1 | Indiana Farm Bur., Baatz No. 1 | S. 11, T.31N., R.13E., Allen Co., Indiana | |
| K-1 | United Fuel, Williams | Coord., 13-M-75, Breathitt Co., Kentucky | —— |
| K-2 | United Fuel, Stamper No. 1 | Coord., 3-V-77, Carter Co., Kentucky | —— |
| K-3 | Inland Gas, Fraley No. 1 | Coord., 24-T-77, Elliott Co., Kentucky | —— |
| K-4 | United Fuel, Pennington No. 1 | Coord., 21-T-76, Elliott Co., Kentucky | —— |
| K-5 | Ashland Oil, Williams No. 8 | Coord., 19-R-79, Johnson Co., Kentucky | —— |
| K-6 | W. E. Lang, Clark | Coord., 18-Y-74, Lewis Co., Kentucky | —— |
| K-7 | United Fuel, Shepherd No. 1 | Lewis County, Kentucky | —— |
| K-8 | United Fuel, James No. 1 | Coord., 19-Q-84, Martin Co., Kentucky | —— |
| C-O-1 | Imperial Oil, Colchester | L-76, Colchester So. Twp., Essex, Co., Ont. | —— |
| O-1 | Flagg Co., Chapman No. 1 | S. 29, Carthage Twp., Athens Co., Ohio | S-1089 |
| O-2 | Midland Explor., Burson No. 1 | S. 28, Rome Twp., Athens Co., Ohio | P-1395 |
| O-3 | Real Corp., Skinner No. 1 | S. 22, Rome Twp., Athens Co., Ohio | S-905 |
| O-4 | El Palso Nat. Gas, Kisor No. 1 | S. 16, Waterloo Twp., Athens Co., Ohio | S-1077 |
| O-5 | Sinking Springs, Parker No. 1 | —Bratton Twp., Adams Co., Ohio | D-3 |
| O-6 | Nat. Assoc. Pet., Gilmore | S. 7, Bedford Twp., Coshocton Co., Ohio | S-761 |
| O-7 | Roberson et al., Geib | L-15, Keene Twp., Coshocton Co., Ohio | S-694 |
| O-8 | Plains Explor., Blicke | S. 22, Bucyrus Twp., Crawford Co., Ohio | S-1122 |
| O-9 | Monk Oil & Gas, Thurston No. 1 | L-16, Porter Twp., Delaware Co., Ohio | S-829 |
| O-10 | J. Adams, Humphreys No. 1 | L-7W, Radnor Twp., Delaware Co., Ohio | S-1103 |
| O-11 | Lancaster Nat. Gas, Brown No. 1 | S. 30, Amanda Twp., Fairfield Co., Ohio | S-438 |
| O-12 | Kubat, Ruff No. 1 | S. 30, Richland Twp., Fairfield Co., Ohio | S-945 |
| O-13 | Graber, Fisher No. 1 | S. 8, Violet Twp., Fairfield Co., Ohio | S-843 |
| O-14 | Kewanee, Hopkins No. 1 | MS-663, Union Twp., Fayette Co., Ohio | S-750 |
| O-15 | Battelle Mem. Inst., Battelle No. 1 | —Columbus (city), Franklin Co., Ohio | S-630 |
| O-16 | Waggoner, Gills No. 1 | S. 28, Perry Twp., Gallia Co., Ohio | S-915 |
| O-17 | Lake Shore Pipeline, Marshall No. 1 | S. 15, Adams Twp., Guernsey Co., Ohio | S-925 |
| O-18 | Kewanee, Amerine No. 1 | S. 33, Benton Twp., Hocking Co., Ohio | S-738 |
| O-19 | Rixleben, Adcock No. 1 | S. 34, Green Twp., Hocking Co., Ohio | S-909 |
| O-20 | Continental, Grover No. 1 | S. 19, Liberty Twp., Jackson Co., Ohio | S-1023 |
| O-21 | Kewanee, Buckeye No. 2 | S. 23, Milton Twp., Jackson Co., Ohio | S-759 |
| O-22 | Nat. Assoc. Pet., Wilt No. 1 | S. 21, Jackson Twp., Knox Co., Ohio | S-783 |
| O-23 | Weed & Assoc., Cambria Clay No. 1 | S. 11, Washington Twp., Lawrence Co., Ohio | S-900 |
| O-24 | Patten, Martin No. 1 | L-2, Hartford Twp., Licking Co., Ohio | S-855 |
| O-25 | Ohio Oil, Johns No. 1 | MS-9930, McArthur Twp., Logan Co., Ohio | S-192 |
| O-26 | J. Adams, Key No. 1 | S. 3, Claridon Twp., Marion Co., Ohio | S-1044 |
| O-27 | Ohio Fuel Gas, Windom No. 1 | S. 1-W, Chester Twp., Meigs Co., Ohio | S-827 |
| O-28 | Sinclair, Longworth No. 1 | L-23, Olive Twp., Meigs Co., Ohio | S-253 |
| O-29 | Morrow Co., Murray No. 1 | S. 12, Meigsville Twp., Morgan Co., Ohio | S-210 |
| O-30 | Brasel & Brasel, Riggs No. 1 | L-16, Bennington Twp., Morrow Co., Ohio | S-1091 |
| O-31 | Pan American, Windbigler No. 1 | S. 18, Troy Twp., Morrow Co., Ohio | S-1033 |
| O-32 | Kewanee, Lake No. 1 | S. 24, Highland Twp., Muskingum Co., Ohio | S-787 |
| O-33 | Kewanee, Mikolojcik No. 1 | S. 19, Perry Twp., Muskingum Co., Ohio | S-838 |
| O-34 | Wehmeyer, Wilkins No. 1 | S. 17, Springfield Twp., Muskingum Co., Ohio | S-779 |
| O-35 | Maddox & Johnston, Burkhart No. 1 | S. 10, Enoch Twp., Noble Co., Ohio | S-639 |
| O-36 | Ridgedale Oil & Gas, Vargo No. 1 | S. 1, Pleasant Twp., Perry Co., Ohio | S-921 |
| O-37 | McMahon et al., Dunlap No. 1 | VMS-4016, Deercreek Twp., Pickaway Co., Ohio | S-1178 |
| O-38 | Continental, Quinsell No. 1 | S. 5, Beaver Twp., Pike Co., Ohio | S-1066 |
| O-39 | Continental, Miller No. 1 | —Pebble Twp., Pike Co., Ohio | P-22 |
| O-40 | Continental, Attinger No. 1 | —Perry Twp., Pike Co., Ohio | P-21 |
| O-41 | Continental, Anderson No. 1 | S. 13, Seal Twp., Pike Co., Ohio | S-1070 |
| O-42 | Southern Triangle, Woodell No. 1 | S. 26, Union Twp., Pike Co., Ohio | S-1121 |
| O-43 | Pan American, Mertler | S. 35, Troy Twp., Richland Co., Ohio | S-1095 |
| O-44 | Kissling Bros., Perie No. 1 | L-407, Concord Twp., Ross Co., Ohio | S-153 |
| O-45 | Continental, Wenzel No. 1 | VMS-4642, Huntington Twp., Ross Co., Ohio | S-1072 |
| O-46 | East Ohio Gas, Haff No. 1 | S. 33, Townsend Twp., Sandusky Co., Ohio | S-895 |
| O-47 | Continental, Jones No. 1 | VMS-14887, Brush Creek Twp., Scioto Co., Ohio | S-1067 |
| O-48 | Smith & Dow Chem., Rose No. 1 | L-82, Green Twp., Scioto Co., Ohio | S-437 |

TABLE 1—*Continued*

| Map Number | Name | Location | State permit or sample number |
|---|---|---|---|
| O-49 | Continental, Dever No. 1 | S. 20E, Madison Twp., Scioto Co., Ohio | S-1045 |
| O-50 | Continental, Shisler No. 1 | S.5-S, Valley Twp., Scioto Co., Ohio | S-1068 |
| O-51 | J. Adams, Holycross No. 1 | VMS-3742, Allen Twp., Union Co., Ohio | S-1011 |
| O-52 | J. Adams, Snyder No. 1 | VMS-15310, Darby Twp., Union Co., Ohio | S-1010 |
| O-53 | J. Adams, Carreker No. 1 | VMS-12400, Liberty Twp., Union Co., Ohio | S-1009 |
| O-54 | Arnold Oil, Hewitt No. 1 | S. 7, Swan Twp., Vinton Co., Ohio | S-640 |
| O-55 | Great Lakes Carbon, Scott No. 1 | S. 20, Liberty Twp., Washington Co., Ohio | S-633 |
| O-56 | Kubat, Sanger | S. 25, Plain Twp., Wayne Co., Ohio | S-914 |
| O-57 | Continental, Eckert | S. 20, Tymochtee Twp, Wyandot, Ohio | S-1071 |
| S-1 | Shell Oil, Foulke No. 1 | Nuttall Twp., Fayette Co., W. Virginia | 123 |
| W-2 | Hope Nat. Gas, Gribble #8517 | Grant Twp., Harrison Co., W. Virginia | 79 |
| W-3 | United Fuel, Damron No. 1 | White Sulphur Twp., Greenbrier Co., W. Va. | 13 |
| W-4 | Texas Co., Dean No. 1 | Williamsburg Twp., Greenbrier Co., W. Va. | 2 |
| W-5 | Baker & Harshberger, Williams No. 1 | Moorefield Twp., Hardy Co., W. Virginia | 1 |
| W-6 | Benedum-Trees, Hill #1668 | Jefferson Twp., Kanawha Co., W. Virginia | 166 |
| W-7 | Columbia Carbon, Campb. Ck. Coal No. 4 | Loudon Twp., Kanawha Co., W. Virginia | 662 |
| W-8 | United Fuel, Arrington No. 1 | Clendenin Twp., Mason Co., W. Virginia | 69 |
| W-9 | ——— | ——— Pocahontas Co, W. Virginia | ——— |
| W-10 | ——— | Union Twp., Preston Co., W. Virginia | ——— |
| W-11 | ——— | Horton Twp., Randolph Co., W. Virginia | ——— |
| W-12 | Hope Nat. Gas, Power Oil #9634 | Walker Twp., Wood Co., W. Virginia | 351 |

## NOMENCLATURE

The nomenclature used in this report follows standard modern usage, except for minor changes. The name "Dayton Formation" is substituted for "Dayton Limestone," because subsurface data indicate that the Dayton is dominantly composed of dolomite in most localities. For the same reason, the name "Brassfield Formation" is used, rather than "Brassfield Limestone."

The Noland Formation, established by Rexroad and others (1965) for strata cropping out in east-central Kentucky and southern Ohio, is accepted by the writer for units occurring in the subsurface of southern Ohio and northeastern Kentucky, where all the members of the Noland can be recognized. In ascending order, these members are: the Plum Creek Clay Member, the Oldham Limestone Member, the Lulbegrud Shale Member, and two equivalent units, the Waco Member south and east of Hillsboro, Kentucky, and the Dayton Member north of Hillsboro, Kentucky, and in southern Ohio. The latter name represents a slight modification from the Dayton Limestone Member as used by Rexroad and others (1965, p. 7).

Outside the area where the Noland Formation is recognized, the Dayton has the status of a formation. The name "Cabot Head Shale" is preferred over the name "Plum Creek Clay Member" for equivalent strata in the northern part of Ohio where the Noland is not present.

The "Clinton" sandstone is used as accepted by the Ohio Geological Survey. This name has been used by drillers and others in Ohio since 1887, when it was applied to a gas-bearing zone in a well near lancaster, Ohio. These beds consist of a series of sandstones separated by shale, and were named Clinton because they were at about the stratigraphic position of Orton's "Clinton" limestone. These sands are not exposed at the surface, nor are they equivalent to the Clinton Formation in New York.

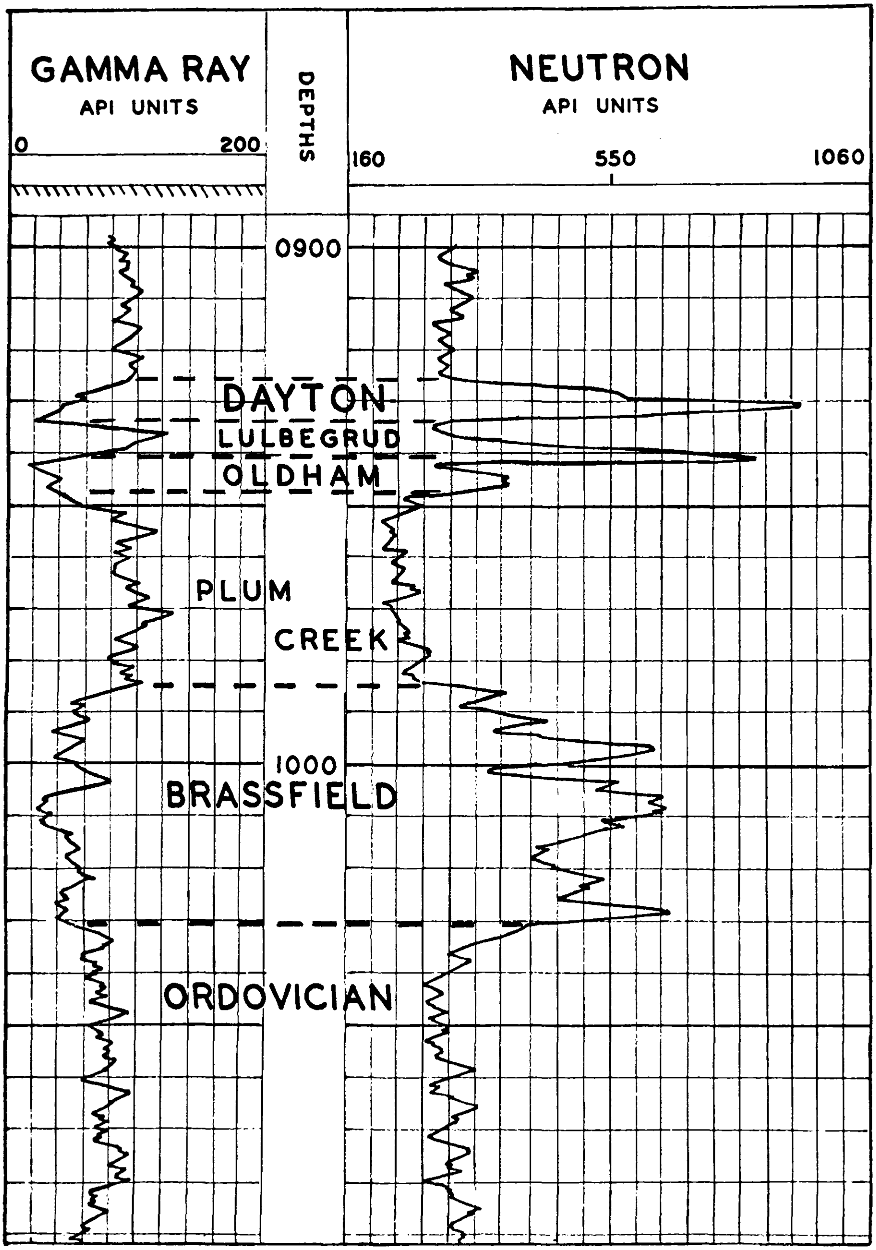


FIGURE 2. Portion of a Gamma-Ray Neutron Log for drill hole 0–39, Pebble Township, Pike County, Ohio.

## STRATIGRAPHY

### *Brassfield Formation*

In 1871 Orton correlated certain limestones in Ohio with the basal Niagaran unit in New York, the Clinton, on the basis of stratigraphic position. This correlation has since been shown to be in error, because the Clinton of New York is now known to be younger. Rocks similar to the Ohio limestones were recognized as a formational unit in Kentucky by Owen as early as 1857. Foerste (1906) gave the name Brassfield to some of these strata exposed in a railway cut near Brassfield, Kentucky. In 1909 he applied this name to the strata in Ohio previously designated as "Clinton" limestone by Orton.

The Brassfield varies in lithology along its outcrop belt, which extends from Lincoln County, Kentucky, northward across the Ohio River to Greene County, Ohio, and thence westward toward the Ohio-Indiana state line. The type section, in and south of Bath County, Kentucky (Rexroad and others, 1965), is divided into three units. The lower Belfast Member here is composed of six feet of bluish-gray, massive, argillaceous, dolomitic limestone. The distinctive appearance and widespread distribution of this lower unit explain its rank as a member of the Brassfield Formation by the Kentucky Geological Survey. Above this are 12 feet of irregular, medium- to thin-bedded dolomitic limestone with thin interbedded shale layers. The upper unit consists of medium-bedded, locally cross-bedded calcarenite, ferruginous in the upper part. Fossils of *Cryptothyrella* [*Whitfieldella*] *subquadrata* and a distinctive crinoid columnal are abundant near the top of the upper unit, the stratum commonly being referred to as the "bead" bed.

In central Bath County, Kentucky, chert-bearing beds three feet thick overlie rocks of Belfast lithology. Although chert is present farther to the south, to the north, from Bath County to Adams County, Ohio, the chert beds form a persistent stratigraphic marker. The Brassfield thickens northward above and below the chert beds. In northwestern Adams County, Kaufmann (1964) recognized five distinct units in the Brassfield Formation, which are listed below, with the oldest at the bottom:

Unit 5. Crinoidal "bead" bed
Unit 4. Interbedded limestones and shales containing ferruginous layer
Unit 3. Massive cherty limestone beds
Unit 2. Shale and carbonate beds
Unit 1. Belfast bed (member)

Northward into Highland, Clinton, Greene, Miami, Montgomery, and Preble Counties, Ohio, the Brassfield lithology undergoes further changes. These include: loss of the persistent chert bed, great reduction in shale content, and disappearance of the ferruginous layer. A generalized description of the northern Brassfield shows a two- or three-fold division, depending on whether or not the Belfast Member is present. Above the somewhat silty and argillaceous Belfast Member is a middle unit composed of light-gray to buff, fine- to coarse-grained, crystalline limestone, with a large content of crinoidal debris. The upper Brassfield unit is composed of medium- to coarse-grained limestone that is pink, red, brown, or gray in color. Some green clay is present as thin partings, lenses, or stringers. Toward the top of this upper unit is a bioclastic unit composed of fragments of corals, brachiopods, and crinoids.

In gross aspect, the Brassfield lithology in the northern area appears more simple. Detailed analysis of any one particular outcrop, however, may result in the subdivision of 30 or 35 feet of Brassfield strata into eight or more units. Possible unconformities between some of these units, as noted by Summerson (1963, p. 31), may partially explain the difficulty of finding the same sequence of units at all the various Brassfield outcrops in the northern area. The Brassfield Formation thickens northward from nearly 22 feet at the type locality to over 50 feet in Adams County, Ohio, and eastward from less than 20 feet in Preble County, Ohio, to 35 feet in Greene County.

Foerste (1906) used a number of characteristics in tracing the Brassfield from the type locality northward into Ohio: the thin ferruginous layer at or near the top of the formation and the generally yellowish-brown colors of the upper limestone layers; the fossiliferous nature of the upper Brassfield, including the "bead" bed, and the widely distributed beds containing abundant *Cryptothyrella*. Foerste found the occurrence of abundant *Cryptothyrella* to coincide with a lack of most of the fauna characteristic of the upper Brassfield. This he interpreted (Foerste, 1906, p. 38) as heralding the introduction of a new fauna as a result of changing ecologic conditions.

### *Noland Formation*

The Noland Formation was proposed by Rexroad and others (1965, p. 14) from Noland Creek, a tributary of the Kentucky River in Madison County, Kentucky, and was defined to include all the strata from the top of the Brassfield Formation to the base of the Estill Shale. The members of the Noland Formation, in ascending stratigraphic order, are the Plum Creek Clay Member, Oldham Limestone Member, Lulbegrud Shale Member, and Waco Member. From Hillsboro, Kentucky, northward into Adams County, Ohio, a thick-bedded limestone occupies the position of the Waco Member, although it differs in some respects from typical Waco strata. In this area the unit is known as the Dayton Limestone Member of the Noland Formation, but north of Adams County, where other members of the Noland are absent, the Dayton retains the formational rank implicit in the original naming by Orton (in 1871, for exposures near Dayton, Montgomery County, Ohio). The fact that each of the present members of the Noland Formation is too thin to be readily mapped at scales in current use is cited by Rexroad (1965) as the reason for reclassification of the four units as members of the Noland Formation.

*Plum Creek Clay Member.*—The Plum Creek Clay was named and described by Foerste (1906) from an exposure of grayish-blue shale with a little interbedded limestone, four to seven feet thick, along Plum Creek in Powell County, Kentucky. Clays occupy the basal part of the member in this area.

The lower contact with the Brassfield is sharp in Adams County, Ohio, although some localities in Kentucky show a transitional lower contact. In areas where there are thin dolomitic limestone beds in the lower part of the Plum Creek, or shales in the upper part of the Brassfield, the "bead" bed is the best physical marker for the contact (Rexroad, p. 16). The upper boundary of the Plum Creek Clay Member appears gradational in most localities. Locally, thin beds of limestone make it difficult to pick the upper contact with the Oldham Limestone Member. This alternation of sedimentary materials is especially prevalent north of Owingsville, Bath County, Kentucky.

*Oldham Limestone Member.*—The type section of the Oldham occurs just north of Oldham Branch in Madison County, Kentucky, along cuts for the Louisville and Atlantic Railroad. Here, between Panola and Brassfield, Foerste (1906) found the best exposures of this unit. The Oldham is a gray dolomitic limestone, with accompanying interbeds of blue-gray shale, approximately ten feet thick.

The Oldham is readily distinguished from the overlying greenish-gray Lulbegrud shales in the area from Stanford, Lincoln County, to southern Bath County, Kentucky. North of Bath County (Rexroad, 1965, p. 19), dolomitic limestones in the Noland occupy the stratigraphic position of the Oldham, but they are shaly and not positively identifiable as Oldham.

*Lulbegrud Shale Member.*—Foerste (1906, p. 50) applied the earlier name of Lulbegrud Clay to approximately thirteen feet of nearly unfossiliferous "blue" shale exposed along Lulbegrud Creek, where it forms the boundary between Powell and Clark Counties, Kentucky. The Lulbegrud ranges in thickness from six feet near Crab Orchard, Lincoln County, Kentucky, to more than 14 feet north of Irvine, Estill County, Kentucky. As much as 19 feet of probable Lulbegrud Shale, consisting of green and reddish-brown shales overlain by the Estill Shale, have been measured at Colfax, Fleming County, Kentucky. Here the upper member of the Noland is absent, either due to erosion or to non-deposition. Northward from Colfax, the Lulbegrud Shale thins, as do the Plum Creek Clay

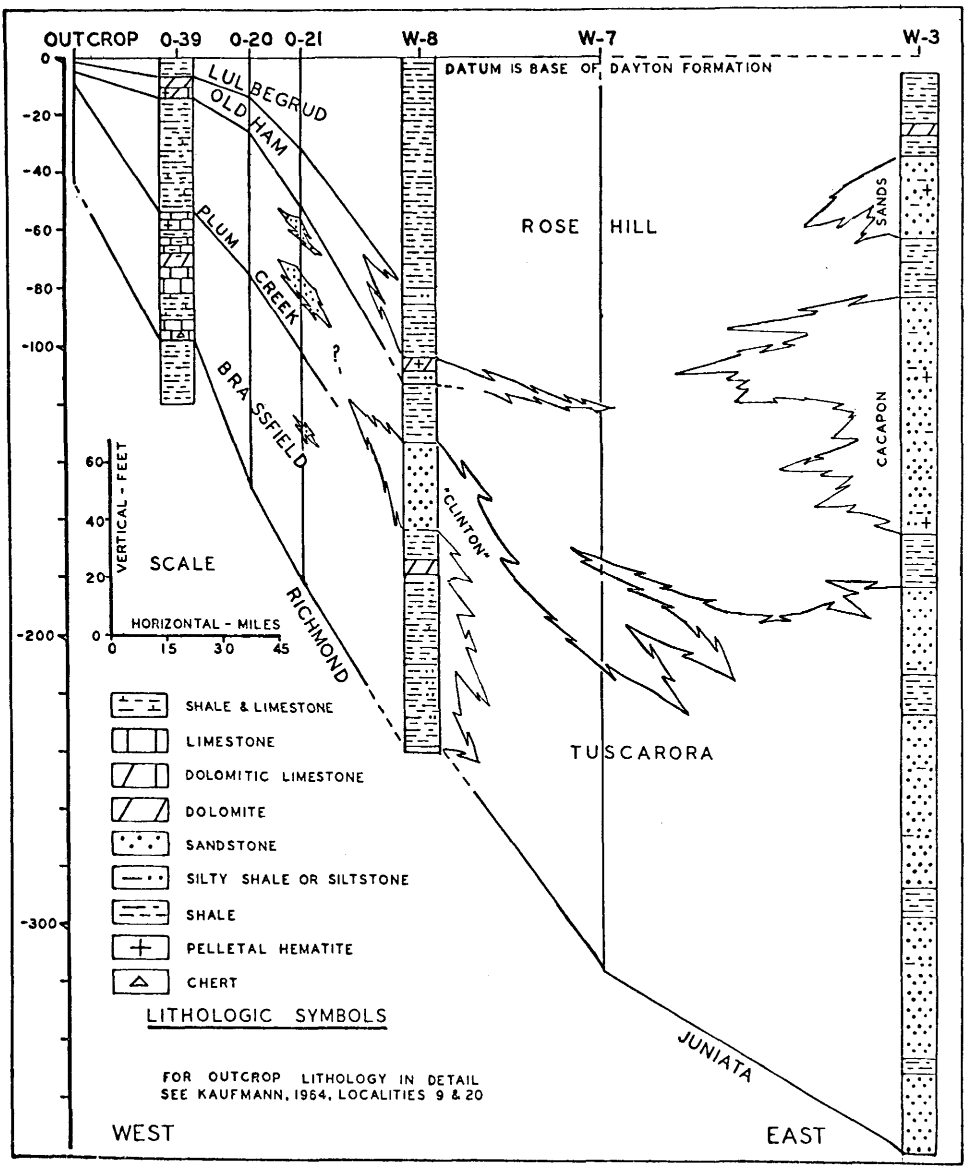


FIGURE 3. East-West Cross Section from northwestern Adams County, Ohio, to southeastern Greenbrier County, West Virginia.

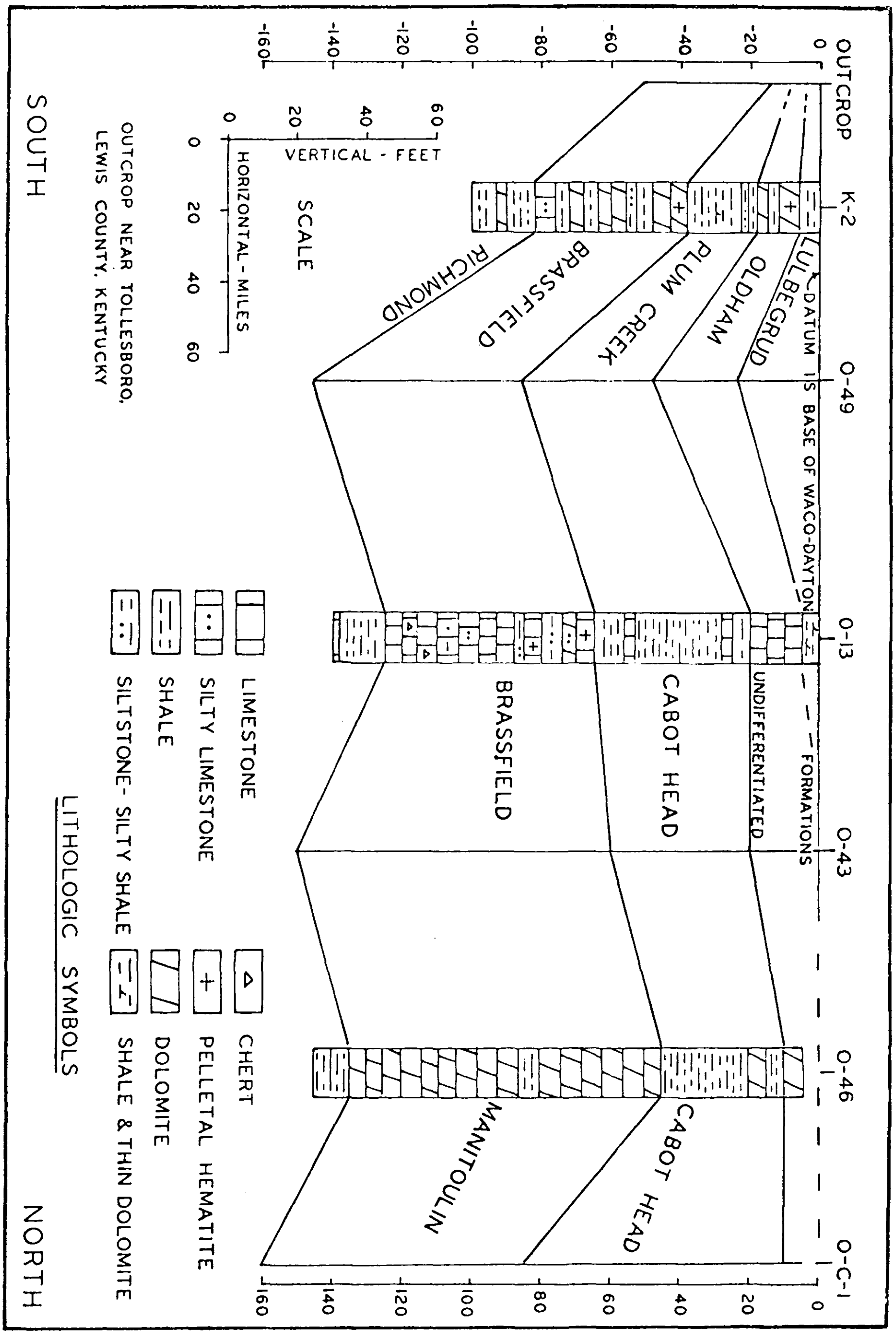


FIGURE 4. North-South Cross Section from Lewis County, Kentucky to Essex County, Ontario.

and Oldham Limestone Members, below the Dayton. The lower part of the Noland wedges out in northern Adams County, Ohio.

The upper boundary of the Lulbegrud Shale is sharp and well defined in most localities where the massive basal limestone bed of the Waco or the carbonate strata of the Dayton are present. Picking the upper contact is more difficult where these key beds are absent, probably due to erosion.

*Waco Member.*—Foerste (1906, p. 33) gave the name Waco Limestone to ten feet of fossiliferous clay and thin interbedded limestones exposed one-half mile east of Waco, Madison County, Kentucky. The use of the word "limestone" reflects the importance of the characteristic basal limestone in correlation, although Foerste was clearly aware of the fact that the formation contained more clay than limestone. Rexroad (1965, p. 20), finding the lithologic designation for such a mixed unit inappropriate, dropped the term "limestone" from the name and reduced the unit to member status. Thus, the Waco is the uppermost member of the Noland Formation and is recognized as such with certainty as far north as Preston, Bath County, Kentucky. Between Preston and Hillsboro, Kentucky, however, the identification of the Waco Member is uncertain.

The Waco is unconformably overlain by the Estill Shale. The presence of glauconite in the green clay or in thin dolomitic partings in the basal part of the unit is important in recognizing the boundary between the Noland Formation and the Estill Shale.

*Dayton Member.*—Orton (1871, p. 149, p. 297–300) named the "Dayton Stone" for strata exposed near Dayton in Montgomery County, Ohio, which typically consist of two to seven feet of gray to greenish-gray, fine-grained, usually dense, hard limestone. Rexroad (1965) considered it to be the uppermost member of the Noland Formation in the area from northern Adams County, Ohio, south to near Hillsboro, Kentucky. It is generally believed that the lower limestone beds of the Waco and the Dayton are equivalent, due to lithologic similarity and stratigraphic position, but because they have not been traced into each other in surface exposures, both names are retained. North of Adams County, Ohio, the Dayton retains formational rank where it unconformably overlies the Brassfield Formation. Glauconite pellets in the base of the overlying Estill Shale and the sharp lithologic change at this boundary in most localities result in a clearly defined upper contact for the Dayton.

The distinctive dove-gray to greenish-gray color, the dense fine-grained texture, and nearly constant subsurface thickness make the Dayton a valuable "key" marker bed for stratigraphic studies, especially in subsurface correlations. The Dayton is used as a datum in the subsurface cross sections included with this report (fig. 3, 4).

## SUBSURFACE INVESTIGATION

Some of the criteria used in identification of formations at outcrops, such as the rusty yellow-brown color or the etched crinoid "bead" bed, are ineffective for correlation in the subsurface, where samples are mainly rock cuttings from drill holes. However, characteristics such as crystallinity, texture, and color of unweathered Brassfield; the presence of chert and oolitic hematite; and the occurrence of certain small megafossils and microfossils retain their usefulness. The loss of precision in carrying units from the outcrop into the subsurface depends both on the nature and identifying characteristics of the formation and the kind of subsurface data available.

In this report, cores and cuttings from drill holes were logged, and units recognized were compared, in terms of thickness, lithology, and stratigraphic sequence, to strata exposed in nearby outcrops. The Miller (O–39) and Attinger (O–40) cores in Pike County, Ohio, were especially helpful in extending surface units of the Silurian into the subsurface, because they permitted an easier and more certain recognition of the units and because they were located near outcrops (fig. 1).

In addition, a very useful tool complementing the use of core chips and cuttings is the gamma-ray neutron log, which records the sharp fluctuations in radioactivity produced by changes in rock type encountered at different depths in a drill hole (fig. 2). The argillaceous character of the Ordovician strata and of the Lulbegrud Shale and Plum Creek Clay Members of the Noland Formation are easily distinguished from the dominantly carbonate lithology of other members of the Noland and the Brassfield Formation. The result is an accurate and detailed definition of the rock units encountered in any drill hole, including even the relatively thin interbeds of carbonate and shale.

The two cores from Pike County mentioned earlier and other drill holes located successively farther east indicate that the lower Silurian section thickens eastward from the outcrop in northwest Adams County. The most striking change in the eastward-thickening wedge of strata occurs between the top of the Brassfield and the base of the Dayton. In the Miller core (O–39) these additional subsurface beds can be divided into a lower unit, consisting of 40 feet of greenish-gray shale with a few thin interbedded limestones, a middle unit of seven feet of dolomite and oolitic or pelletal hematite in a calcareous matrix, and an upper unit of about six feet of green and reddish-brown shale. The Dayton Member overlies this upper unit. These three units thin to a combined thickness of less than ten feet at the reference outcrop 22 miles to the southwest in northern Adams County (Locality 20, Kaufmann, 1964, p. 181–182).

Some geologists consider these three upper units to be part of the Brassfield Formation; Perry (1962) has included similar strata in the subsurface of eastern Kentucky in the Brassfield. After careful comparison of Silurian outcrops in Adams County, Ohio, and in Lewis County, Kentucky, with cuttings and core chips from drill holes, I believe that these beds are lithologically equivalent to the Plum Creek, Oldham, and Lulbegrud Members of the Noland Formation in east-central Kentucky.

Brassfield strata were examined at the type locality in Madison County and near Tollesboro, Lewis County, Kentucky. Similar beds, identified in well cuttings, were traced from Carter County, Kentucky, to Licking and Delaware Counties, Ohio. The hematite, the distinctive brown, yellow, and pink coloring, and the argillaceous content which are characteristic of the upper units of the Brassfield farther south are absent as the formation is traced northward through western Morrow County. However, strata that correspond lithologically to middle units in the Brassfield as found exposed in Montgomery and adjacent counties, can be traced northward into Sandusky County (drill hole O–46). Well cuttings show hematite is absent from the Brassfield and all other Silurian beds in northwestern Ohio. Hunter (1960) suggests that the necessary conditions for the formation of hematite were lacking in the northern part of the Appalachian Basin during the Silurian Period. However, a thick zone of hematite is present in what appears to be the basal Silurian section of the Baatz No. 1 drill hole in Allen County, Indiana. This is indicated by hematite symbols on the left edge of figure 5. If hematite from this drill hole is Silurian, then either conditions were locally favorable for deposition of hematite or hematite beds had wider distribution in western Ohio during the Silurian and were subsequently eroded from the Arch. In either case, the absence of the typical upper units of the Brassfield in these northwestern Ohio counties (Crawford, Marion, Sandusky, and others) indicates that the Cincinnati-Findlay Arch was already influencing the sedimentary record in the early part of the Silurian.

An unconformable relationship at the top of the Brassfield has been noted at surface exposures in southwestern Ohio by several investigators, including Foerste (1895) and Kaufmann (1964). In outcrops north of Adams County, where the Dayton overlies the Brassfield Formation, the Plum Creek, Oldham, and Lulbegrud Members are missing.

An unconformable relationship roughly similar to that noted by Kaufmann (1964, p. 72) was observed in drill hole O–52 in Union County, Ohio. Drill cuttings show that approximately 22 feet of shale separate the Dayton Formation from the Brassfield. This shale was traced northward by means of drill-hole cuttings into Sandusky County, where it is continuous with the Cabot Head Shale. The

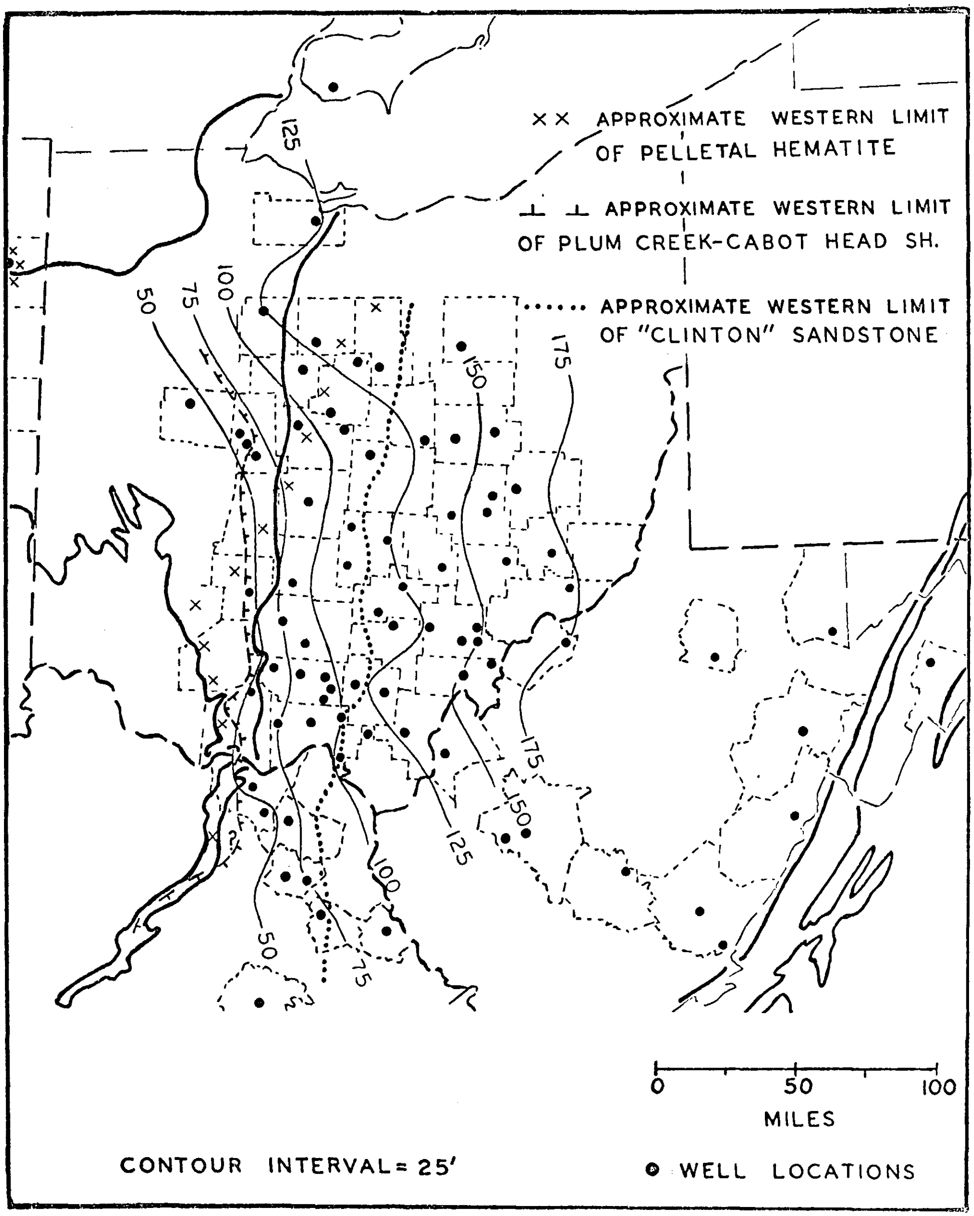


FIGURE 5. Isopach Map showing thickness of rocks in the lower part of the Silurian section (top of the Plum Creek-Cabot Head Shale to top of the Ordovician) in Ohio and northeastern Kentucky.

presence of the Cabot Head Shale in the subsurface of Sandusky County has been noted by several investigators, including Sparling (1965). A few miles to the northwest of O–52, this shale was absent in drill holes O–51 and O–53, and the Dayton rests directly on the Brassfield. The section recorded from the O–52 drill hole appears below.

0–52 Section. Partial log of the John Adams, Snyder No. 1, Darby Township, Union County, Ohio. No elevation available.

| *Depth below Surface* | *Unit* | *Thickness in Feet* |
|---|---|---|
| | Silurian | |
| 473 ft. | Dayton Formation | 15 (?) |
| | 8. Very light gray and tan, fine- to nearly medium-crystalline glauconitic dolomite | 10 |
| | 7. Light-brown, tan, and some gray, partly coarse-crystalline dolomite; contains some pyrite; possibly Oldham | 5 |
| 488 ft. | Cabot Head Shale | 22 |
| | 6. Soft, greenish-gray shale | 22 |
| 510 ft. | Brassfield Formation | 45 |
| | 5. Light-brown and partly green mottled, calcareous, medium-crystalline dolomite | 10 |
| | 4. Light-brown, yellow, and gray-green, medium-crystalline, slightly glauconitic dolomite | 5 |
| | 3. Gray to brown, medium-crystalline limestone and dolomite; bioclastic | 10 |
| | 2. Light-brown, buff, and gray-brown, fine- and coarsely-crystalline limestone and dolomite; dolomite is partly glauconitic; unit contains some fossiliferous chert | 15 |
| | 1. Light-brown, fine- and coarse-crystalline limestone; slightly argillaceous | 5 |
| 555 ft. | Ordovician | |
| | Limestone and shale | |

Some 75 to 90 miles east of the Union County, Ohio, drill hole (O–53), the dominantly carbonate Brassfield section changes to a dominantly shale section, with some siltstone and sandstone beds including the lower part of the "Clinton" sandstone. In drill holes in Coshocton (O–6, O–7), Knox (O–22), and Muskingum (O–32, O–33, O–34) Counties, Ohio, thin beds of limestone with interbedded hematite, sandstone, and shale occur above a thick section of shale. The following section recorded from the O–6 hole shows the general thickening of the section that has occurred between drill holes O–52 in Union County and O–6 in Coshocton County. Note also the change in facies occurring at the position of the Cabot Head Shale and Brassfield Formation, indicated by the presence of the "Clinton" sandstone.

0–6 Section. Partial lithologic log of National Assoc. Petrol., Gilmore No. 1, Bedford Township, Coshocton County, Ohio. Elevation: 1096 feet.

| *Depth below Surface* | *Unit* | *Thickness in Feet* |
|---|---|---|
| | Silurian | |
| | Estill Shale | |
| 3376 ft. | Dayton Formation | 10 |
| | 13. Green and gray, fine- and very finely-crystalline limestone and dolomite; partly glauconitic | 10 |
| 3386 ft. | Oldham Limestone | 28 |
| | 12. Light-brown, gray, and yellow, medium-crystalline limestone; contains crinoid fragments | 28 |
| 3414 ft. | Cabot Head Shale | 16 |
| | 11. Gray shale | 6 |
| | 10. Calcareous oolitic hematite, shale and limestone | 10 |

| Depth below Surface | Unit | Thickness in Feet |
|---|---|---|
| 3430 ft. | "Clinton" sandstone (and shale) | 51 |
| | 9. Light-gray, fine sandstone with dolomitic and siliceous cement ... 6 | |
| | 8. Mostly gray shale ... 10 | |
| | 7. Light-gray to white sandstone ... 7 | |
| | 6. Gray shale ... 8 | |
| | 5. White sandstone ... 4 | |
| | 4. Gray shale ... 6 | |
| | 3. White porous sandstone (tested oil) ... 10 | |
| 3481 ft. | Brassfield Formation | 6 |
| | 2. Light-brown and gray-brown, medium-crystalline limestone and dolomite; some oolitic hematite ... 6 | |
| 3487 ft. | Unassigned Silurian (?)—possibly equivalent to part of the Brassfield Formation | 68 |
| | 1. Mostly gray shale with some brown shale and thin interbeds of siltstone ... 68 | |
| | Ordovician | |
| 3555 ft. | Juniata red shale and siltstone | |

In central Ohio the exact stratigraphic position of the "Clinton" sandstone is uncertain. The section recorded above from the O–6 drill hole in Coshocton County shows an upper sandstone (Unit 9) and a middle sandstone (Unit 7) interbedded with shale lithologically similar to the Cabot Head Shale. The upper sandstone probably correlates with the stray "Clinton" and the middle sandstone with the first "Clinton" of Multer (1963, p. 8). A lower divided sandstone (Units 3 and 5 in hole O–6) occurs just above strata identified as Brassfield and is probably correlative to Multer's second "Clinton". In drill hole O–22 in Knox County, Ohio, this lower sandstone appears to intertongue with Brassfield carbonates, a relationship that indicates a correlation between the Brassfield and second "Clinton" in this well. Sandstone equivalent to the second "Clinton" (Multer, 1963) is correlated with the Cabot Head Shale in the Canton, Ohio, area by Pepper (1953). Pepper's correlation and the relationship of the second "Clinton" sandstone to the Brassfield in drill hole O–22 support Multer's conclusion that the age of the "Clinton" sandstone may vary in different parts of Ohio.

The contact between the Brassfield Formation and the Cabot Head Shale presents a problem in some subsurface localities. Data from drill holes in Licking and Fairfield Counties (O–24, O–13) indicate that shales at the position of the Cabot Head are interbedded with oolitic hematite and carbonates of Brassfield description. Gamma-ray neutron logging of this interval shows certain tracings characteristic of the Cabot Head Shale section in other wells, but the interbedded carbonates in the lower two-thirds to three-fourths of this "shale" section seem identifiable as Brassfield. These drill holes are located just east of the 100-foot isopach line (fig. 1, 5). The combined thickness of the Brassfield Formation and Plum Creek Clay Member in drill hole O–20 in Jackson County to the south is about the same as the Brassfield-Cabot Head thickness recorded in drill holes O–24 and O–13. However, in the Jackson County hole, the section is clearly divisible into the Plum Creek Clay Member, consisting almost entirely of shale (45 feet), and the Brassfield Formation, consisting mostly of carbonates (73 feet). These figures can be compared with an average of 20 feet of sharply defined Cabot Head Shale and 90 feet of probable Brassfield (?) strata at drill holes O–24 and O–13. The example just cited indicates that, where such intertonguing occurs between the Brassfield limestone and Cabot Head Shale, an isopach of their combined thickness (fig. 5) is more meaningful than an isopach of the Brassfield Formation alone.

Less than 30 miles to the east of their outcrop in east-central Kentucky, the different members of the Noland Formation can be differentiated in cuttings from drill hole K–2 in Carter County, whose section is given below.

K–2 Section. Partial lithologic log of United Fuel Gas, Stamper No. 1, Coord. 3–V–77, Carter County, Kentucky. Elevation: 846 feet. (Formation depths in Table 2).

| *Unit* | *Thickness in Feet* |
|---|---|
| Silurian | |
| Estill Shale | |
| Noland Formation | 47 |
| Waco Member, approx | 8 |
| 10. Greenish-gray and light-gray, finely crystalline, dense dolomite that is slightly glauconitic; interbedded with reddish-brown and green shale | 5 |
| 9. Tan to green silty dolomite and dolomitic siltstone | 3 |
| Lulbegrud Shale Member | 6 |
| 8. Green and reddish-brown interbedded shale | 6 |
| Oldham Limestone Member | 12 |
| 7. Light-brown to grayish, medium crystalline, partly mottled dolomite; oolitic hematite present along with interbedded shale | 12 |
| Plum Creek Clay Member | 21 |
| 6. Gray, grayish-green and reddish-brown shale with some interbeds of gray to light brown, medium crystalline dolomite | 21 |
| Brassfield Formation | 44 |
| 5. Brownish-gray, medium- to coarse-crystalline, fossiliferous dolomite and hematite | 9 |
| 4. Reddish-brown and greenish-gray shale | 6 |
| 3. Light-brown, fine- and medium-crystalline, calcareous dolomite; some tan to green siltstone and traces of tan chert | 10 |
| 2. Mostly gray shale with some light-brown silty dolomite | 12 |
| 1. Brown arenaceous limestone and fine calcareous sandstone | 7 |
| Ordovician | |
| Interbedded carbonates, shale and siltstone | |

The members of the Noland Formation can be traced northward from the K–2 drill hole in Carter County, Kentucky, across the Ohio River into Scioto County, Ohio, where all the members (as well as the underlying Brassfield) have thicker intervals in the vicinity of drill hole O–49. Here the Noland is 92 feet thick and the Brassfield is approximately 61 feet thick. The Noland can be traced northward in the subsurface to drill hole O–20 in Jackson County and then on to the west, where it is present in cuttings and cores from holes O–41 and O–39, Pike County, Ohio. Its thickness ranges from 95 feet at hole O–20 to 70 feet and 60 feet, respectively, at holes O–41 and O–39.

Northward into Fairfield, Licking, and Richland Counties, Ohio, the Noland loses its identity. The Oldham Limestone Member is present in the vicinity of drill holes O–13 in Fairfield County and O–24 in Licking County, but not the Lulbegrud Shale Member. The Dayton Member and the Plum Creek Clay Member were also present in these two holes and are the only members of the Noland that can be traced northward into Richland County, Ohio (drill hole O–43). The Dayton could not be identified with certainty in drill cuttings from hole O–46 in Sandusky County, Ohio, although the Plum Creek Clay Member, or its equivalent, the Cabot Head Shale, was identified in this drill hole.

About 85 miles to the south (and slightly west) of hole O–46 in Sandusky County, the Dayton is present in the subsurface at holes O–51, O–52, and O–53 in Union County, Ohio. East and southeast of Union County, characteristic Dayton lithology can be recognized in cuttings from drill holes in Coshocton (hole O–6), Meigs (hole O–27), Gallia (hole O–16), and Athens (hole O–4) Counties, Ohio. Eastward into Wood and Mason Counties, West Virginia, the Dayton appears to be equivalent to dolomite and dolomitic siltstone in the lower part of the Rose Hill Formation (holes W–8 and W–12). Thin beds of slightly glauconitic dolomite and siltstone (Dayton ?) extend as far east as Greenbrier County, West Virginia (hole W–3), thereby providing a basis for the datum in figure 3.

The thickness of the Dayton in the subsurface in Ohio generally ranges between five and 15 feet. Cuttings from 70 per cent of the drill holes utilized in this report show the Dayton to be composed entirely of dolomite; in the remaining drill holes, the Dayton consists of either limestone or mixed limestone and dolomite, and in West Virginia dolomitic siltstone is present.

The Plum Creek Clay Member was traced northward from drill hole K–2 in Carter County, Kentucky, to Fairfield and Licking County, Ohio, (holes O–13, O–24) where it is continuous with the Cabot Head Shale (fig. 1, 4). The presence of the Cabot Head Shale in northern and central Ohio has been recorded by several geologists, including Rittenhouse (1949). Approximately 45 feet of Cabot Head Shale is successively overlain by Oldham and Dayton carbonate beds in the vicinity of drill hole O–24 in Licking County. Some 40 miles to the west, a similar shale, about 15 feet thick, was recognized in hole O–52 in Union County, Ohio. This shale is underlain by Brassfield strata and overlain by a few feet of possible Oldham (?) beds, and these in turn are overlain by typical Dayton carbonates. Because the Lulbegrud Shale Member is absent in drill hole O–24 in Licking County and has not been identified in drill holes north and west of hole O–24, it appears that the shale above the Brassfield in hole O–52 correlates with the Cabot Head Shale (Plum Creek Clay Member). The Cabot Head Shale wedges out a few miles to the west and is not present at drill holes O–51 and O–53 in Union County, Ohio. Other investigators (including Rittenhouse 1949) show the Cabot Head Shale continuing eastward from central Ohio into Pennsylvania and West Virginia. Shale believed equivalent to the Cabot Head Shale (Plum Creek Clay Member) is indicated to be present at hole W–8 in Mason County, West Virginia (fig. 3).

## SUMMARY OF SUBSURFACE INVESTIGATIONS

In this report the Brassfield Formation and the members of the Noland Formation (Plum Creek Clay, Oldham Limestone, Lulbegrud Shale, and Waco-Dayton) are traced from outcrops in southwestern Ohio and east-central Kentucky into the subsurface.

The Brassfield Formation was found to have great linear extent in a general north-south direction (table 2). It was traced in well cuttings from Johnson County, Kentucky (drill hole K–5), northward into Sandusky County, Ohio (drill hole O–46), where it is continuous with the Manitoulin Dolomite across Lake Erie in Ontario (drill hole C–O–1). According to Freeman (1951), the Brassfield seas spread westward from Ohio and Kentucky into the Ozarks and at least as far south as northern Alabama and Mississippi. To the east, thin carbonate beds of the Brassfield intertongue with the lower "Clinton" sandstone in central and eastern Ohio, and are eventually traced into part of the Tuscarora Formation in West Virginia (table 2). The boundary between the Brassfield and the overlying Plum Creek-Cabot Head Shale in the subsurface is difficult to determine in some places. The nature of this contact and the change in lithology between drill holes O–20, O–13, and O–24 indicate a facies relationship.

The members of the Noland Formation have generally been classified as part of the Brassfield in earlier subsurface studies because these shale and carbonate beds are much like strata in the upper part of the Brassfield. The scarcity of strategically located drill holes and the possibility of disordered or contaminated rotary drill cuttings was a hindrance to detailed subsurface studies. Recently, the wider availability of gamma-ray neutron logs has added reliability and precision to sample logs made from drill cuttings. This radioactive logging procedure is capable of detecting relatively thin shale and carbonate beds such as those that comprise the Noland Formation.

The Plum Creek Clay Member was traced northward from Johnson County, Kentucky (drill hole K–5) into Pike, Fairfield, Licking, and Sandusky Counties (drill holes O–39, O–11, O–24 and O–46) in central and northern Ohio, where it is equivalent to the Cabot Head Shale of earlier investigators (including Rittenhouse 1949). The Plum Creek Clay-Cabot Head Shale interval thins toward the Cincinnati Arch in western Ohio, perhaps as a result of both erosion and facies change. The approximate western limits of the Plum Creek Clay-Cabot Head Shale in Ohio is shown in figure 5. Eastward, in central and eastern Ohio, these shales intertongue with the upper "Clinton" sandstone. A seemingly equivalent section in the West Virginia subsurface consists of basal shale in the Rose Hill Formation and uppermost sandstone in the Tuscarora Formation (fig. 3).

TABLE 2

*Subsurface data from drill holes*

(Dept of rock units below surface in feet)

A. West-east cross section

| Number | Elevation | Oldham | Cabot Head-Plum Creek | "Clinton" or Tuscarora | Brassfield | Ordovician |
|---|---|---|---|---|---|---|
| O–39 | 681 | 940 | 947 | —— | 986 | 1030 |
| O–20 | 959 | 2075 | 2090 | —— | 2137 | 2210 |
| O–21 | 765 | 2870 | 2890 | 2910 | 2945 | 3025 Est. |
| W–8 | 597 | —— | —— | 4475 | —— | 4580 |
| W–7 | 984 | —— | —— | 6215 | —— | 6320 |
| W–3 | 2841 | —— | —— | 6825 | —— | 7020 |

B. South-north cross section

Cabot Head-

| Number | Elevation | Lulbegrud | Oldham | Cabot Head-Plum Creek | Brassfield | Manitoulin | Ordovician |
|---|---|---|---|---|---|---|---|
| K–2 | 846 | 1646 | 1652 | 1664 | 1685 | —— | 1729 |
| O–49 | 585 | 1892 | 1918 | 1940 | 1977 | —— | 2038 |
| O–13 | —— | 1320? | 1325 | 1340 | 1375 | —— | 1435 |
| O–43 | 1270 | —— | —— | 2105 | 2145 | —— | 2240 |
| O–46 | 641 | —— | —— | 765 | 800 | 800 | 890 |
| C–O–1 | 606 | —— | —— | 1260 | —— | 1335 | 1410 |

The middle members of the Noland Formation, the Oldham Limestone and the Lulbegrud Shale, are the least widespread. Drill-hole data indicate their presence in the subsurface of Adams, Pike, Scioto, Jackson, Meigs, Athens, Hocking, Guernsey, and Muskingum Counties, Ohio. In addition these rock units are present in Carter, Lewis, Johnson, Elliott, and possibly other counties of Kentucky. The presence of the Oldham Limestone Member is essential for separating the Lulbegrud Shale Member from the Plum Creek Clay Member in the subsurface. The Oldham has a somewhat greater occurrence to the north than the Lulbegrud. Drill cuttings from Pickaway County drill hole O–37 and from Licking County drill hole O–24 show the Dayton resting upon Oldham. Eastward, across the Ohio border into West Virginia, the Lulbegrud and Oldham seem to merge with the lower part of the Rose Hill Formation in the subsurface.

In most of Ohio, the Dayton is easily identified by the predominant dove-gray to greenish, finely-crystalline dense appearance of these carbonate strata and the persistent glauconite in the overlying shale. In northern Ohio (drill holes O–8 in Crawford County and O–46 in Sandusky County), the Estill shale, including the basal glauconitic bed that normally overlies the Dayton, is absent because of erosion (Rittenhouse, 1949). Drill cuttings and gamma-ray neutron logging indicate the presence of an approximately ten-foot unit of dolomite above the Cabot Head Shale in drill holes O–8 and O–46 which does not correspond to characteristic Dayton lithology, although these beds may be correlative with the Dayton. In my opinion, the Dayton cannot be recognized with certainty in Crawford and Sandusky Counties, Ohio.

The Dayton Formation gradually changes character in eastern Ohio and western West Virginia, where it occurs as the first carbonate interval below the top of the Rose Hill Formation in drill hole W–12, Wood County, West Virginia. This is somewhat below the middle of the Rose Hill section in this well. In drill hole W–8 in Mason County, West Virginia, the probable equivalent of the Dayton consists of silty dolomite and dolomitic siltstone, again located a few feet below the middle of the Rose Hill. Although the Dayton beds could not be identified in the subsurface of eastern West Virginia, the widespread distribution of these beds in Ohio and neighboring parts of Kentucky and West Virginia make it a valuable stratigraphic marker for subsurface investigations.

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